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## **Moisture monitoring of wood-frame walls with and without exterior insulation in a Midwestern U.S. cold climate**

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### **ABSTRACT**

Continuous exterior insulation is becoming more common in North American above-grade walls in both retrofit applications and new construction, as a means to improve the thermal performance of wall assemblies. Although moisture performance of wood-frame wall assemblies has been studied extensively, the drying capability of wall assemblies with exterior insulation and an interior vapor retarder in cold climates is not well characterized. This study monitored the hygrothermal performance of wall assemblies with and without exterior insulation under high and low interior humidity conditions and with intentional wetting of the wood structural panel sheathing. Moisture content and temperature of standard 38 mm × 140 mm wood framing and 11 mm thick oriented strand board (OSB) sheathing were measured over a two-year period in eight different wall assemblies, each with north or south orientation, in a conditioned test structure in Madison, Wisconsin. Wall configurations differed primarily in the interior vapor retarder (kraft paper or polyethylene film) and the exterior insulation (none, expanded polystyrene, extruded polystyrene, or mineral wool). OSB sheathing was wetted in a controlled manner at three different times of year to investigate drying response. Wintertime moisture accumulation in OSB in the tested climate zone was not a concern except in the wall with no exterior insulation and interior kraft vapor retarder, though rapid drying occurred in springtime. Drying of OSB after controlled wetting events was generally faster during warm weather than cold weather; faster with exterior insulation than without during cold weather; faster with vapor-open exterior insulation than low-permeance exterior insulation during cold weather; and faster with interior kraft vapor retarder than polyethylene.

### **KEYWORDS**

moisture performance, hygrothermal performance, continuous insulation, building envelope, durability

### **INTRODUCTION**

The building envelope is a key component affecting overall building energy use. Continuous exterior insulation is an increasingly common strategy to improve overall thermal performance in North American above-grade wall assemblies in both retrofit applications and new construction. This approach is particularly relevant for wood-frame construction in cold climates. While Performance Compliance Paths in the International Energy Conservation Code (IECC) (ICC, 2015) offer flexibility in the design of exterior walls, the Prescriptive Compliance Path requires wood-frame walls located in cold climates (IECC Climate Zone 6 or higher) to incorporate continuous insulation at a minimum thermal resistance of 0.88 m<sup>2</sup>·K/W (5 h·ft<sup>2</sup>·°F/Btu or “R-5”). This is often implemented with a combination of cavity insulation and continuous exterior insulation.

Long-term moisture performance of exterior wall assemblies is critical because moisture accumulation can lead to degradation of materials and poor indoor air quality. Moisture control strategies for exterior wall assemblies need to address sources of moisture from the interior and exterior of the building and the ways in which moisture migrates, including bulk water intrusion, uncontrolled air leakage, and vapor diffusion (TenWolde and Rose, 1996). In addition, the capacity to dry out when wetting occurs (either during construction or over the service life of the building) can improve the moisture tolerance and reduce the risk of problems, but the drying potential may be a concern for some wall assemblies that are insulated and air sealed to levels required by current model energy codes.

A recent literature review (Trainor and Smegal, 2017) concluded that adding exterior insulation to wood-frame walls in North American cold climates in nearly every case did not increase the risk of moisture-related durability problems. Continuous exterior insulation raised the temperature of wood structural members in exterior walls during cold weather (relative to walls without exterior insulation), thereby reducing the potential for wintertime moisture accumulation (Tsongas, 1991; Straube, 2011). With regard to drying potential, several studies found that walls with vapor-open exterior insulation allowed drying to the outside at a faster rate than walls with exterior foam insulation (Maref *et al.*, 2011; Fox *et al.*, 2014; Trainor *et al.*, 2016). In addition, faster drying rates were observed during spring and summer in exterior insulated walls without an interior polyethylene vapor barrier than in those with polyethylene (Craven and Garber-Slaght, 2014).

The studies mentioned above investigated a variety of wall configurations but did not include 38 by 140 mm framing (nominal 2×6) with 0.88 m<sup>2</sup>·K/W (R-5) exterior insulation, which meets the “R-20+5” IECC Prescriptive Compliance Path in cold climate zones (IECC Climate Zone 6 or higher). For this configuration, the ratio of exterior insulation to cavity insulation is not sufficient to permit the use of only a Class III interior vapor retarder (such as latex paint on gypsum board). The present study was initiated to characterize the moisture performance of 140 mm wood-frame wall assemblies with and without exterior insulation in a cold climate location. Specific objectives were to monitor wall assembly moisture and temperature conditions under ambient environmental conditions with high and low interior humidity conditions, and to characterize wall assembly drying rates after intentional wetting of the wood structural panel sheathing.

## METHODS

Monitoring was carried out in a conditioned test structure located in Madison, Wisconsin (IECC Climate Zone 6). This cold climate has 4,074 heating degree days (18°C basis; 1981–2010 mean); 2015 and 2016 were warmer than normal, both with about 90% of the historic mean heating degree days. The 17.2 m x 4.9 m test structure was oriented with the long dimension running east to west. It had a preservative-treated wood post and beam foundation with an insulated floor. The 38 x 140 mm wood stud walls were refurbished for this study to create eight different north and south facing test bays (Figure 1). Each test bay was 1.2 m wide and 2.2 m high and consisted of three cavities with studs 406 mm on center. Test bays were isolated with a composite trim board on the exterior and by adding a 38 x 140 mm stud separated from the existing stud of the adjacent test bay using an impermeable self-adhering membrane. An entry door was located on the north side of a central area that houses the data acquisition system and heating and cooling equipment. Winter mean interior temperature was 20 °C; mean interior relative humidity (RH) was 42% during the first winter and 34% during the second winter. Summer mean interior conditions were 25 °C with RH between 45% and 55%.

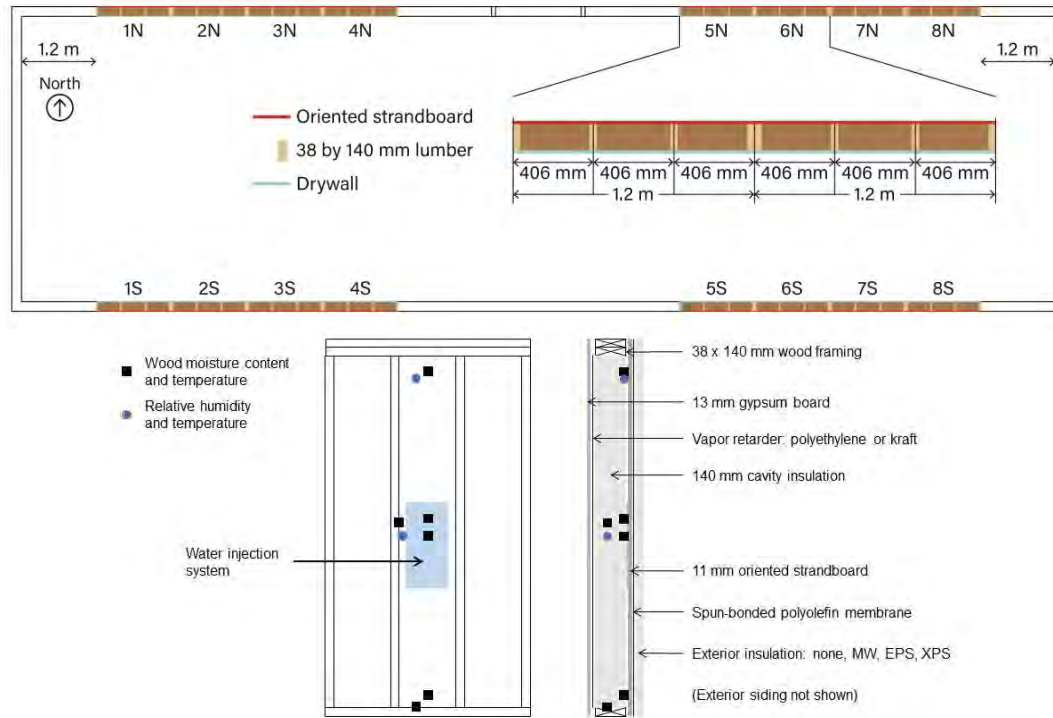


Figure 1. (top) Plan view of test structure with labelled test bays. (bottom) Wall elevation and section showing sensor layout.

All wall assemblies included vinyl siding, spun-bonded polyolefin house wrap, oriented strand board (OSB) sheathing, fiberglass batt cavity insulation ( $3.7 \text{ m}^2 \cdot \text{K/W}$  or R-21), and interior gypsum drywall. Gasketing was installed between the framing and drywall for airtightness, and the drywall was finished with latex primer and latex paint. Test walls differed in the type of interior vapor retarder, water-resistive barrier, and exterior insulation (Table 1). Walls 1 and 2 provided base cases with no exterior continuous insulation (CI); Wall 1 had asphalt-coated kraft paper facing on the fiberglass batt insulation, whereas Wall 2 had 0.15 mm polyethylene sheet (with unfaced batt insulation). The remaining walls included one of the following exterior insulation materials: 38 mm mineral wool (MW) insulation ( $1.1 \text{ m}^2 \cdot \text{K/W}$  or R-6); 38 mm expanded polystyrene (EPS) insulation ( $1.1 \text{ m}^2 \cdot \text{K/W}$  or R-6); or 25 mm extruded polystyrene (XPS) insulation ( $0.88 \text{ m}^2 \cdot \text{K/W}$  or R-5). Walls 1-7 had ordinary spun-bonded polyolefin membrane installed just exterior of the OSB sheathing, whereas Wall 8 used a “crinkled” version of the same material, structured to create vertical channels and a small air gap between the OSB sheathing and XPS insulation.

Table 1. Wall configurations.

Wall	Label	Interior Vapor Retarder	House Wrap	Exterior Insulation
1	No CI, kraft	Kraft paper	Flat polyolefin	None
2	No CI, poly	Polyethylene	Flat polyolefin	None
3	MW, kraft	Kraft paper	Flat polyolefin	38 mm MW
4	MW, poly	Polyethylene	Flat polyolefin	38 mm MW
5	EPS, kraft	Kraft paper	Flat polyolefin	38 mm EPS
6	XPS, kraft	Kraft paper	Flat polyolefin	25 mm XPS
7	XPS, poly	Polyethylene	Flat polyolefin	25 mm XPS
8	XPS, kraft, crinkled	Kraft paper	Crinkled polyolefin	25 mm XPS

Each test bay had an identical set of sensors installed in the central cavity (of the three that make up a bay; Figure 1). Wood moisture content (MC, percentage based on dry mass) and temperature were measured hourly at six locations in each test bay: four sensor pairs were located in OSB sheathing at various heights, one in the bottom plate, and one in a stud at mid-height. MC values in OSB were based on resistance measurements using the calibration of Boardman *et al.* (2017). Two additional sensors measured RH and temperature in the center of the cavity and at the interior surface of the OSB. Indoor RH and temperature and weather conditions were also recorded on site. Further details are given in Boardman *et al.* (2018).

Each wall assembly was subjected to an identical water injection schedule at three different times during the study. A shop towel was fastened to the interior side of the OSB in the center cavity to serve as a reservoir for the injected water (Figure 1), which was introduced through a vinyl tube from the interior near the drywall surface (Van Straaten, 2003). Each injection had a volume of 40 mL, which wetted the shop towel without water running down the OSB sheathing. The first series of injections occurred in late summer, starting August 13, 2015, with one injection per day for three days (total of 120 mL). The second series of injections occurred in late fall, starting November 6, 2015, and lasted five days (total of 200 mL). The last series of injections occurred the following spring, starting May 20, 2016, and lasted 4 days (total of 160 mL).

## RESULTS AND DISCUSSION

OSB moisture content was higher in winter than summer, as illustrated in Figure 2 for north-facing walls (away from the wetting device). Two further trends are noted: first, walls with kraft vapor retarder had higher OSB MC in winter than corresponding walls with polyethylene; second, walls with exterior insulation had lower OSB MC than the base walls. Wintertime moisture contents were highest in the base wall with kraft vapor retarder; the peak was above 30% MC in the first winter and about 23% MC in the second winter, whereas the base wall with polyethylene vapor retarder remained below 16% MC. The difference is a result of water vapor migration from interior humidification through the more permeable kraft vapor retarder. Similar trends were observed in the south-facing walls, though the peak moisture contents were typically not as high as in the north-facing walls. The lower moisture levels in the south walls are due to the slightly higher temperature (as a result of solar radiation), but this effect was small and not consistent in all results. More consistent was the result that walls with exterior insulation had lower moisture levels than the base walls.

The response of OSB moisture content to water injections is depicted in Figure 3 for sensors placed within the field of the wetting device in north-facing walls. All wall configurations had a rapid increase in OSB MC after the water injections. Several observations about drying rates are noted. First, the drying rates in general were faster for the first injection (Aug 2015) and third injection (May 2016) than the second injection (Nov 2015). This was expected because drying is slower at colder temperatures. Second, for all three injections the walls with a kraft vapor retarder dried more rapidly than corresponding walls with polyethylene, consistent with the higher vapor permeance of kraft allowing drying to the interior. Third, for the second injection (in colder weather), walls with exterior insulation generally dried faster than the corresponding base walls, due to the exterior insulation keeping the OSB warmer. Fourth, the walls with exterior MW insulation dried faster than corresponding walls with exterior XPS insulation after the second injection; this is a result of the higher vapor permeance of MW and is consistent with prior research. Further analysis supporting these observations is presented by Boardman *et al.* (2018).

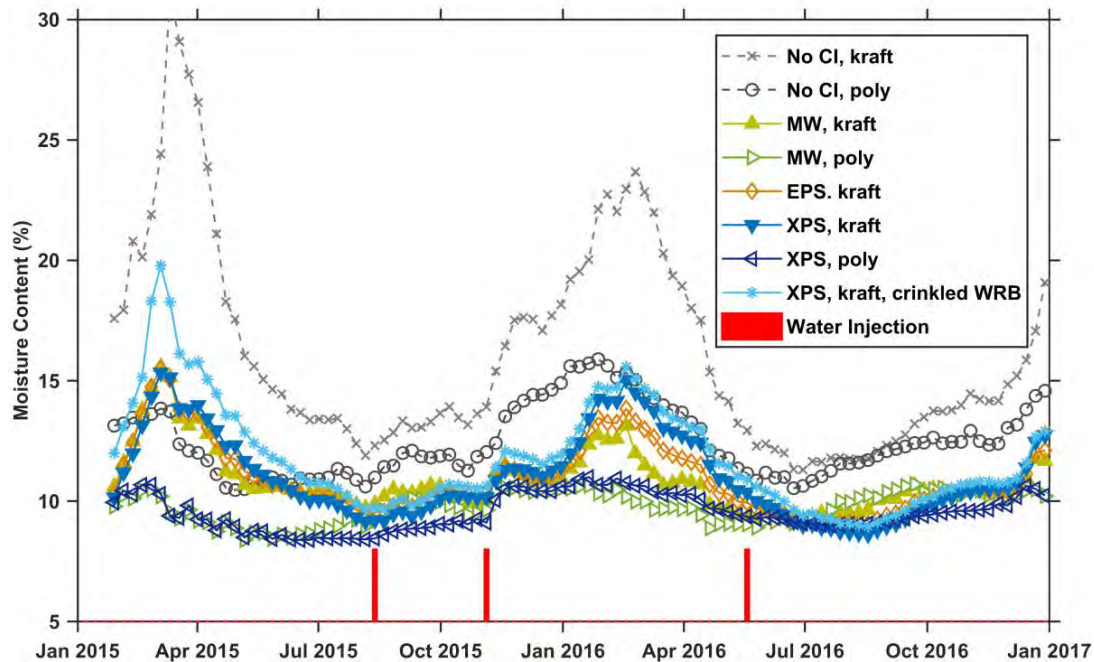


Figure 2. Weekly average moisture content of OSB in north-facing walls (average of sensors in OSB near top plate and bottom plate).

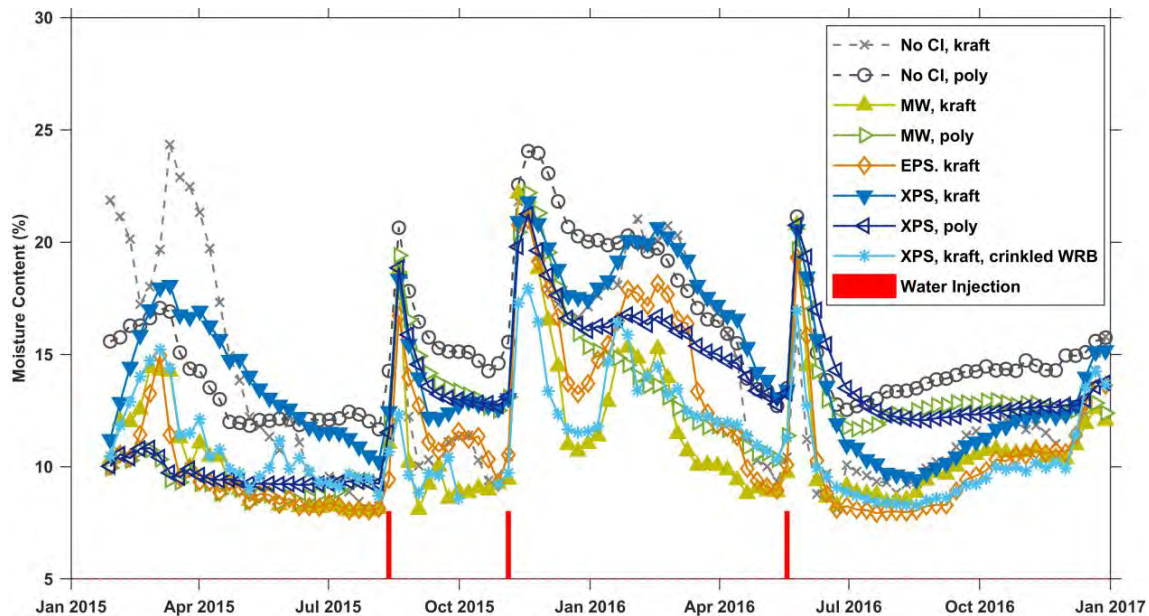


Figure 3. Weekly average moisture content of OSB at mid-height in north-facing walls (average of sensors in the field of the water injection system).

## CONCLUSIONS

This cold-climate monitoring study provides further support to the conclusion that adding continuous exterior insulation lowers the wintertime moisture content in wood structural panel sheathing. The drying rate of a wall with low-permeance exterior insulation and interior polyethylene after modest wetting was similar to a corresponding base wall without exterior

insulation. Drying rates were faster for walls with an interior kraft vapor retarder than polyethylene. In cold weather walls with vapor-open exterior insulation dried faster than base walls and walls with low-permeance exterior insulation. Under cold weather conditions and high interior humidity levels, a kraft vapor retarder did not prevent moisture accumulation in the OSB sheathing in the base wall without exterior insulation, though it dried out quickly in warmer weather. This study did not quantify risk of moisture damage. Further work is ongoing to combine this field study with laboratory and modeling research to develop strategies to minimize moisture risks in energy efficient wood-frame walls.

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